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13. ABSTRACT (Maximum 200 words)

This grant investigated various aspects of defect-engineered compound semiconductor films and heterostructures. The research studied in detail the impact of intentional defect introduction into semiconductor heterojunction device structures. The impact of intentional defect introduction is on the formation, properties and structure of heterointerfaces is of particular interest in these studies. We continued the development of sub-micron probes to obtain highly localized information on electronic structure and optical properties, coupled with the topology of the film using Near Field Scanning Optical Microscopy as a photoluminescence probe and as a scanning photoreflectance probe. This grant also looked at the means to use localized stress to alter the motion of dislocation developed at a lattice-mismatched heterointerface.

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Defect Engineering and Defect Complexes in Compound Semiconductors Alloys

Final Report

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Statement of the Research Problem

This grant investigated various aspects of defect-engineered compound semiconductor films and heterostructures. The research studied in detail the impact of intentional defect introduction into semiconductor heterojunction device structures. The impact of intentional defect introduction is on the formation, properties and structure of heterointerfaces is of particular interest in these studies. We continued the development of sub-micron probes to obtain highly localized information on electronic structure and optical properties, coupled with the topology of the film using Near Field Scanning Optical Microscopy as a photoluminescence probe and as a scanning photoreflectance probe. This grant also looked at the means to use localized stress to alter the motion of dislocation developed at a lattice-mismatched heterointerface.

Major Research Results

Photoreflectance in Near-field Optical Scanning Microscopy

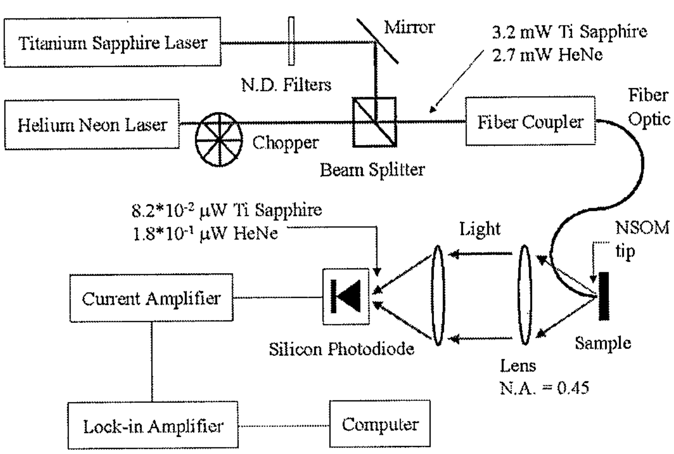

Figure 1: In the Photoreflectance NSOM system the pump and probe beams are combined in a laser-to-single-mode-fiber coupler. The light is brought to the surface through a single-mode fiber, and reflected light is collected by a lens. The PR signal is detected at a photodiode. A computer controls the tuning of the titanium sapphire laser to the wavelengths of interest and controls data acquisition. Typical light levels are shown.

A novel Near-field Scanning Optical Microscopy (NSOM) was developed to obtain simultaneous topology, photoluminescence and photoreflectance (PR) spectra. PR spectra from GaAs surfaces were obtained and the local electric fields were calculated. Sub-wavelength resolution is expected for this technique and achieved for PL and topology measurements. Photovoltages, resulting from the high intensity of light at the NSOM tip, can limit the spatial resolution of the electric field determination.

Photoreflectance (PR) spectroscopy can be used to determine surface electric field in the depletion region, the surface Fermi level (E_F), doping density, doping type, and the band gap energy (E_g). These quantities are important for device optimization and their measurement in the micron and submicron size regime is becoming increasingly important.

PR is a form of electromodulation spectroscopy. Minority and majority carriers are created in a direct band gap semiconductor by excitation with above band gap light via a pump source that is chopped at a typical frequency, ν, of 100 – 1000 Hz. A second tunable light

source serves as the probe and is then reflected from the sample's surface. The reflected light will contain both a DC and an AC component. The AC component of the reflected light is modulated at the pump frequency. The normalized AC component, $\Delta R/R$, is obtained as the PR signal. The magnitude of the measured quantity $\Delta R/R$ is typically 10^{-2} to 10^{-4}. When the wavelength of the probe light is scanned, Franz-Keldysh oscillations (FKOs) can be seen in the $\Delta R/R$ spectra due to electric field modulation of the reflectivity of the sample. These oscillations are strongest near the probe photon energy $E_{probe} = E_g$, and decay in intensity as the energy is increased. Only an exponential decay in the PR spectrum is seen for energies less than E_g. The extrema in the FKO's are related to the internal electric field, F, within the semiconductor

The Photoreflectance-NSOM (PR-NSOM) set-up is shown in Figure 1. This system uses a 5mW HeNe and a few mW of a Titanium Sapphire (TiS) laser as pump and probe sources, respectively. The two laser beams are combined using a beam splitter and are coupled into a single mode fiber optic using a laser-to-single-mode-fiber coupler. Delivery of both lasers through the same fiber insures that the pump and probe are coincident on the sample. Topographic feedback and scanning is achieved using a commercial scanning control system. The fiber tip is mounted on a quartz tuning fork. Measurement of the tuning fork impedance allows for topographic feedback, similar to other systems reported in the literature.

The sample used in this study was a UN^+ GaAs structure consisting of a thin undoped layer (70nm) of GaAs grown on top of a highly doped layer. This structure has been previously used for PR studies, since it exhibits a large number of FKO due to the large uniform built-in electric field and small broadening parameter in the low doped-region. The electric field at the semiconductor surface in these structures is determined by both the difference between the surface Fermi level position and the Fermi level in the underlying n^+ region, and the thickness of the undoped region. This system requires about 3 hours to gather a 100 data point PR spectrum, where each datum represents the average of 25 sampling of the PR signal.

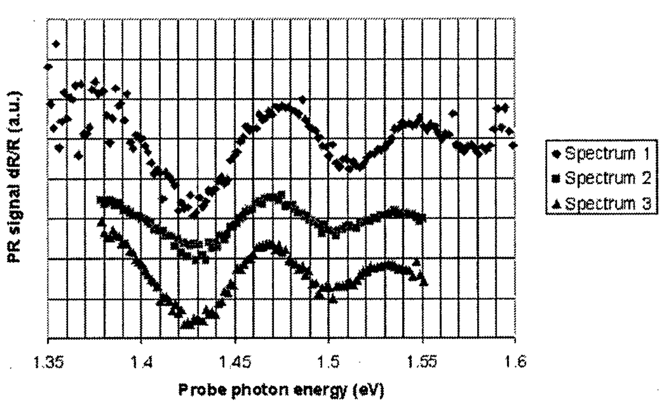

Figure 2: Photoreflectance spectra from the PR-NSOM system indicating that the measured electric field decreases with increasing light intensity due to the photovoltage effect. Spectrum 1 to 3 represent an increase in incident optical power density and represent electric fields of 71, 66, and 61 kV/cm, respectively.

PR spectra obtained from this PR-NSOM system on the UN^+ structure are shown in Figure 2. The spectra exhibit about 4 FKOs. The low signal levels and the achieved signal-to-noise ratio of the NSOM limit the number of FKO observed in these spectra. The period of FKO in these spectra clearly decreases from spectrum 1 to spectrum 3. The calculated fields are 71, 66, and 61 kV/cm for spectra 1 through 3, respectively. The decrease in the measured electric field observed for the three spectra is related, at least in part, to

the increasing incident optical power density through the generation of a photovoltage.

Spatial variation in the PL have been achieved on lithographically-patterned samples on length scales in the <1 μm size regime. This same NSOM tip has been used to gather PR spectra, indicating an upper bound for the spatial resolution. The PR measurement should have higher or equivalent resolution as the PL measurement. We have achieved ~0.1 μm resolution in the PL measurements, but could not detect intentional changes in the PR on this same length scale by using known changes in the surface electric field. Changes in the field should occur over a lower length scale, estimated here to be on the order of ~70nm for these samples. High photovoltage effects, masking smaller changes in the local field, must be reduced in order to fully utilize this technique. Elevated sample temperatures, or the use of electrical modulation would reduce this photovoltage.

Oxygen-related Deep Levels in $Al_{0.5}In_{0.5}P$ Grown by MOVPE

Oxygen related defects in Al-containing materials have been determined to degrade luminescence efficiency and reduce carrier lifetime and affect the performance of light emitting diodes and laser diodes utilizing these materials. We have used the metal-organic source diethyl aluminum ethoxide (DEAlO) to intentionally incorporate oxygen-related defects during growth of $Al_{0.50}In_{0.50}P$ by metal-organic vapor phase epitaxy (MOVPE). The incorporated oxygen forms several energy levels in the bandgap with energies of 0.62 to 0.89 eV below the conduction band detected using Deep Level Transient Spectroscopy. Secondary Ion Mass Spectroscopy measurements of the total oxygen concentration in the layers show a direct correlation to the measured trap concentrations. Several other energy levels are detected that are not correlated with the oxygen content of the film. DLTS measurements reveal four defects; two of which are directly related to the presence of oxygen. The concentration of these levels depends on the concentration of oxygen in the film, supporting the theory that oxygen incorporation leads to several levels with different energies. A deep level at 0.40 eV below the conduction band is related to a stoichiometric defect, possibly a cation-vacancy complex.

NSOM Cross-Sectional Measurements of Crystalline GaAs Solar Cells

In collaboration with Prof. Reuben Collins of the Colorado School of Mines, Near Field Scanning Optical Microscopy (NSOM) was used to study cleaved edges of GaAs solar cell devices. Using visible light for excitation, the NSOM acquired spatially resolved traces of the photocurrent response across the various layers in the device. For excitation energies well above the bandgap, carrier recombination at the cleaved surface had a strong influence on the photocurrent signal. As the excitation energy approached the bandgap, a more ideal photocurrent trace was obtained, demonstrating that NSOM photocurrent measurements are sensitive to surface recombination. The NSOM measurements directly observed the effects of a buried minority carrier reflector/passivation layer.

Fabrication of InAs/AlSb/GaSb Heterojunction Bipolar Transistors on Al_2O_3 Substrates by Wafer Bonding

High frequency integrated circuit applications of GaSb-based materials are hampered by the lack of a suitable lattice matched insulating substrate. Although several notable device and circuit

demonstrations have been made using these materials, the absence of lattice-matched, insulating substrates remains an issue, particularly for minority carrier devices. Bulk-grown GaSb is the most widely available substrate for the near lattice-matched epitaxial growth of these materials. GaSb is not, however, available in semi-insulating form. A semi-insulating substrate or insulating platform is critical for many applications due to high parasitic capacitances which arise when metal interconnect lines are placed above conductive substrate materials. Sapphire substrates have the dielectric properties suitable for such applications, but are not suitable for direct heteroepitaxial growth due to the large lattice and thermal expansion coefficient mismatch. Wafer bonding was used fabricate InAs/AlSb/GaSb-based heterojunction bipolar transistors (HBTs) on an insulating sapphire substrate through a low temperature bonding process that results in a high bond strength and permitted the mechanical and chemomechanical removal of the initial GaSb substrate. The use of selective etches allows for the retaining the epitaxial device layers over virtually the entire wafer area. The device structures were characterized by high-resolution x-ray diffraction (HRXD) both as-grown, still on the native GaSb substrate, and after transfer to the sapphire substrate. Minimal degradation of the transferred layers occurred in the bonding and substrate removal process. The resulting transferred structures were fabricated into functional HBTs exhibiting a DC current gain of ~5.

Carbon and Hydrogen induced Yellow Luminescence in Gallium nitride grown by Halide vapor phase epitaxy

Yellow luminescence (YL) from GaN was systematically investigated through the intentional introduction of carbon, from propane, and excess H_2 during growth by the halide vapor phase epitaxy technique. All GaN films were studied by photoluminescence, X-ray diffraction and Hall measurements. The unintentionally doped GaN showed undetectable or very weak YL signal, while both C-doping and H_2 addition resulted in a significant enhancement of YL. The blue- and red-shift of the YL band of the C-doped and 'H_2-grown' GaN with the increasing temperature indicated that different mechanisms existed in these two cases. The temperature dependence of the integrated intensity of the YL band of both groups implicated that shallow donors, not 'shallow' acceptors participated the YL transition and that there were more than one radiative recombination channel within the YL band.

Influence of C, N and O Ion-implantation on Yellow Luminescence

Influence of C, N and O ion-implantation on the yellow luminescence (YL) of halide vapor phase epitaxy (HVPE) and metal-organic vapor phase epitaxy (MOVPE) grown GaN has been studied by photoluminescence (PL) spectroscopy. For the HVPE-grown samples, only C implantation produces a significant enhancement of YL while its corresponding overall PL integrated intensity is only ~72% of its original value. Implantation of O or N do not appreciably change the YL but decrease the BE integrated intensities by a factor of ten. The full-width-half-maximum (FWHM) of the BE band expanded to about 1.4 × of the original value in all three cases. These results indicate that one source of the YL is strongly correlated to incorporation of C into the GaN film. The C-induced defect complexes in GaN are optically active while O or N does not lead to any new luminescence features. The variable-temperature PL measurements on the C-implanted HVPE-grown GaN reveal that the FWHM of the YL band increases linearly and the peak energy of the YL changes very little with the increasing measurement temperature, while the integrated intensity of the YL band decreases monotonically. This trend of the YL FWHM and peak energy

with the measurement temperature can be explained by a two-channel transition model. For MOVPE-grown GaN films, all ion-implanted samples exhibit a significant loss of both the YL and overall integrated PL intensity. Residual C contamination in the MOVPE samples could be large compared to the additional ion-implanted carbon leading to a reduced impact of the ion-implanted carbon.

Lateral Epitaxial Overgrowth of GaSb on GaSb and GaAs Substrates by Metalorganic Chemical Vapor Deposition

Lateral epitaxial overgrowth of GaSb on GaSb and GaAs substrates patterned with SiO_2or Si_3N_4 films by metalorganic chemical vapor deposition was accomplished using trimethylgallium and trimethylantimony. Transmission electron microscopy measurements show that coalesced films grown on GaSb substrates exhibit defect-free materials, while those on GaAs substrates show regular, small-angle crystal tilting originating from large lattice mismatch. The crystal tilting does not occur in films grown over windows smaller than 3 μm.

Photoluminescence and Photoluminescence Excitation Spectroscopy of In -situ Er-Doped and Er-Implanted GaN Films Grown by Hydride Vapor Phase Epitaxy

Photoluminescence (PL) and photoluminescence excitation (PLE) spectroscopy have been carried out at 6K on the 1540 nm $^4I_{13/2} \Rightarrow {}^4I_{15/2}$ emission of Er^{3+} in in situ Er-doped and Er-implanted GaN grown by hydride vapor phase epitaxy (HVPE). The PL and PLE of these two different Er-doped HVPE-grown GaN films are compared with Er-implanted GaN grown by metal organic chemical vapor deposition (MOCVD). In the in situ Er-doped HVPE-grown GaN, the lineshape of the broad PLE absorption bands and the broad PL bands is similar to that in Er-doped glass. The PL spectra of this in situ Er-doped sample are independent of excitation wavelength, unlike the PL of the Er-implanted GaN. These PL spectra are quite different from the site-selective PL spectra observed in the Er-implanted GaN, indicating that the seven different Er^{3+} sites existing in the Er-implanted MOCVD-grown GaN are not observed in the in situ Er-doped HVPE-grown GaN. Four of the seven different Er^{3+} sites observed in the Er-implanted MOCVD-grown GaN annealed at 900°C under a flow of N_2 are present in the Er-implanted HVPE-grown GaN annealed at 800°C in an NH_3/H_2 atmosphere.

Impurity Incorporation and the Surface Morphology of MOVPE Grown GaAs

The impact of impurity incorporation on the development of the surface morphology of GaAs epilayers, grown by metal-organic vapor phase epitaxy (MOVPE), has been systematically investigated. A variety of different doping elements, including Mg, Zn, C, Si, O and Se, were used to study the interaction between the impurity atoms and GaAs surface. Impurity atoms with smaller atomic weight, belonging to group II and VI, have a larger influence on the surface morphology than the other dopants. Different chemical sources for carbon doping were also used to explore the effect of surface growth chemistry on the formation of surface features. The epilayer surface morphology was affected by the combination of several physical and chemical factors. Factors influencing the impact of an impurity on the growth front evolution were developed based on the interaction between the impurity atoms and the surface step structures.

Effect of Interface Roughness on Performance of AlGaAs/InGaAs/GaAs Resonant Tunneling Diodes

The interface roughness of AlGaAs/InGaAs/GaAs double-barrier-quantum-well structures were controllably altered by changing substrate surface misorientation and growth interruption time at the MOVPE growth interfaces. Atomic force microscopy (AFM) and X-ray reflectivity measurements were used to quantify the interface morphology within the structure. AFM was used to obtain the direct information on the morphology of the quenched growth front, while X-ray reflectance measurements were used to determine the structures of the buried interfaces. These measurement results were combined to obtain a comprehensive and quantitative understanding of the interface morphology within the structure. The low temperature photoluminescence (PL) of the structure and the low temperature I-V characterization of the resonant tunneling diodes, based on this quantum well structure, is measured to quantitatively access the impact of hetero-interface roughness on optical and electronic transport properties of the structure. The experimental interfacial roughness data were used as an input to a numerical simulation of device performance.

Listing of Publications Associated with this Grant:

1. "Hydrogen Induced Yellow Luminescence in GaN Grown by Halide Vapor Phase Epitaxy," R. Zhang and T.F. Kuech, J. Electron. Mater. 27 (1998) L35-L39.
2. "Oxygen-related Defects in $In_{0.5}(Al_xGa_{1-x})_{0.5}P$ Grown by MOVPE," J.G. Cederberg, B. Bieg, J.W. Huang, S.A. Stockman, M.J. Peanasky, and T.F. Kuech, Mat. Res. Soc. Symp. Proc. Vol. 484 (1998) 611-615.
3. "Carbon and Hydrogen Induced Yellow Luminescence in Gallium Nitride Grown by Halide Vapor Phase Epitaxy," R. Zhang and T.F. Kuech, Mat. Res. Soc. Symp. Proc. Vol. 482 (1998) 709-714.
4. "Influence of C, N and O Ion-Implantation on Yellow Luminescence", R. Zhang, L. Zhang, N. Perkins, and T.F. Kuech, Mat. Res. Soc. Symp. Proc. 512 (1998) 321-326.
5. "Incorporation of Er into GaN by in-situ Doping During Halide Vapor Phase Epitaxy", R. Zhang and T.F. Kuech, Mat. Res. Soc. Symp. Proc. 512 (1998) 327-331.
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10. "Gallium Nitride Growth using Diethylgallium Chloride as an Alternative Gallium Source", Ling Zhang, Rong Zhang, Marek P. Boleslawski, and T.F. Kuech, MRS Internet J. Nitride Semicond. Res. 4S1, G3.62 (1999) and Mat. Res. Soc. Symp. Proc. 537 (1999)
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12. "Microstructure of epitaxial (InGa)As on a borosilicate glass-bonded compliant substrate", S.E. Babcock, K.A. Dunn, M. Zhou, J.L. Reeves, T.F. Kuech, D.M. Hansen, and P.D. Moran, Materials Science Forum, 294-296 (1999) 783-6.
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17. "Near-field scanning optical microscopy cross-sectional measurements of crystalline GaAs solar cells", M. K. Herndon, W. C. Bradford, R. T. Collins, B. E. Hawkins, T. F. Kuech, D. J. Friedman and S. R. Kurtz, Appl. Phys. Lett. 77 (2000) 100-102.
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21. "Lateral epitaxial overgrowth of GaSb on GaSb and GaAs substrates by metalorganic chemical vapor deposition", S.S. Yi, D.M. Hansen, C.K. Inoki, D.L. Harris, T.S. Kuan and T.F. Kuech, Appl. Phys. Lett. 77 (2000) 842-4.

Presentations with Peer-reviewed, Published Abstracts

1. "Nitride Based High Power Devices: Transport Properties, Linear Defects and Goals", Z. Bandic, P.M. Bridger, E.C. Piquette, T.F. Kuech, T.C. Mc Gill, MRS Spring 1998 Meeting, San Francisco, CA, April 13-17, 1998.
2. "Influence of C, N and O ion-implantation on yellow luminescence", R. Zhang, L. Zhang, N. Perkins and T.F. Kuech, MRS Spring 1998 Meeting, San Francisco, CA, April 13-17, 1998.
3. "Incorporation of Er into GaN by in-situ doping in Halide Vapor Phase Epitaxy", Rong Zhang and T.F. Kuech, MRS Spring 1998 Meeting, San Francisco, CA, April 13-17, 1998.
4. "Oxygen Related Defects In $In_{0.5}(Al_xGa_{1-x})_{0.5}P$ Quaternary Alloys Grown By MOVPE", J. G. Cederberg, B. Bieg, J.- W. Huang, M. J. Peanasky, S. A. Stockman, T. F. Kuech, The Ninth International Conference on Metal Organic Vapor Phase Epitaxy (ICMOVPE IX), LaJolla, CA, May 31- June 4, 1998.
5. "DLTS Studies Of Deep Levels In Er Doped GaAs And $Al_xGa_{1-x}As$ Grown By MOVPE", J. G. Cederberg, T. D. Culp, B. Bieg, D. Pfeiffer, C. H. Winter, K. L. Bray, and T. F. Kuech, The Ninth International Conference on Metal Organic Vapor Phase Epitaxy (ICMOVPE IX), LaJolla, CA, May 31- June 4, 1998.
6. "Effect Of Interface Roughness On Performance Of AlGaAs/InGaAs/GaAs Resonant Tunneling Diodes", Mr. Jiang Li, T. F. Kuech, A. Mirabedini, L. J. Mawst, D. Botez, D. E. Savage, and R. J. Matyi, The Ninth International Conference on Metal Organic Vapor Phase Epitaxy (ICMOVPE IX), LaJolla, CA, May 31- June 4, 1998.

7. "Influence of hydrogenation and dehydrogenation on yellow luminescence in GaN films", R. Zhang, L. Zhang and T.F. Kuech, Electronic Materials Conference, University of Virginia, Charlottesville, VA, June 24-26, 1998.
8. "OMVPE Growth of Highly Mismatched InGaAs Grown on Compliant Substrates", P.D. Moran, J.G. Cederberg, D.M. Hansen, R.J. Matyi, and T.F. Kuech, Ninth Biennial OMVPE Workshop, Ponte Vedra Beach, Florida, May 23-27, 1999.
9. "A Comparison of Experimental and Calculated HRXD Spectra of Mismatched InGaAs Films Grown on Borosilicate Glass-Bonded GaAs Compliant Substrate Structures", P. D. Moran, D. M. Hansen, J. G. Cederberg, K. A. Dunn, L. J. Mawst, S. E. Babcock, R. J. Matyi, and T. F. Kuech, Electronic Materials Conference, University of California - Santa Barbara, Santa Barbara, CA, June 30- August 2, 1999.
10. "Photoreflectance Near-Field Scanning Optical Microscopy", Charles Paulson , Jingxi Sun, Arthur B. Ellis, Leon McCaughan, and Thomas Kuech, MRS Fall 1999 Meeting, Boston, MA, P2.1, Nov. 28 – Dec. 3, 1999.
11. "Dependence of Film Relaxation on Film Mismatch and Thickness in InGaAs on Glass-Bonded GaAs Compliant Substrates", P.D. Moran , D.M. Hansen and T.F. Kuech, MRS Fall 1999 Meeting, Boston, MA, O5.2, Nov. 28 – Dec. 3, 1999.
12. "NSOM Study of Semiconductor Surfaces, Interfaces and Grain Boundaries", R. T. Collins, M. K. Herndon, A. Gupta, V. Kaydanov, T. Ohno, D. J. Friedman, S. R. Kurtz, J. M. Olson, T. F. Kuech, B. Hawkins, American Physical Society Meeting, Minneapolis, MN, March 20-24, 2000.
13. "Lateral Epitaxial Overgrowth of GaSb on GaAs and GaSb Substrates by Metalorganic Chemical Vapor Deposition", S.S. Yi, D.M. Hansen, T.F. Kuech, C.K. Inoki, D.L. Harris, T.S. Kuan, Materials Research Society Meeting, San Francisco, April 24-28, 2000.
14. "Development of Alternative Magnesium Source Compounds For Epitaxial Film Growth, C.H. Winter, A.R. Sadique, D. Pfeiffer, and T.F. Kuech, International Conference on Metalorganic Vapor Phase Epitaxy X, Sapporo, JAPAN, June 5-9, 2000.
15. "Cross Sectional Scanning Probe Studies of Hydride Vapor Phase Epitaxy GaN Films", Julia W.P. Hsu, David V. Lang, Shulin Gu, Thomas F. Kuech, Electronic Materials Conference, University of Denver, Denver, CO, June 21- June 23, 2000.
16. "Lateral Epitaxial Overgrowth of GaSb on GaAs and GaSb Substrates", C. K. Inoki, D. L. Harris, T. S. Kuan, S. S. Yi, D. M. Hansen, and T. F. Kuech, Microscopy and Microanalysis 2000 Meeting, Philadelphia, PA, Aug 13-17, 2000.
17. "Antimonide-Based Heterojunction Bipolar Transistor Structures on Sapphire Substrates", P. Moran, D. Chow, A. Hunter, and T. Kuech, 27th International Symposium on Compound Semiconductors, Monterey, CA, Oct. 2-6, 2000.
18. "Mapping Optical and Electronic Variations in Lateral Epitaxial Overgrown GaN Films", Julia W.P. Hsu, M.J. Matthews, D.V. Lang, S. Richter, D. Abusch-Magder, R.N. Kleiman and A.M. Sergent, Shulin Gu and T.F. Kuech, Mat. Res. Soc. Fall Mtg., Boston, MA, Nov. 26 – Dec. 1, 2000.

Personnel Supported:

Graduate Students Receiving Support

All listed have been partial support. Their research activities are indicated.

Name	Position	Activity
Jeffrey Cederberg	ChE Graduate Student, Ph.D. granted	Growth of Oxygen Doped Alloys
Yang-Chun Cheng	Current Materials Science Program Ph.D. Graduate Student	Materials Integration
Fransiska Dwikusuma	Current Ph.D. ChE Graduate Student	GaN Preparation
Brian Hawkins	Current Ph.D. ChE Graduate Student	GaSb MOVPE Growth
Ari Lukoff	Current ChE Undergraduate Student	NSOM tip development
Zhiyan Liu	Current Ph.D. ChE Graduate Student	GaSb Surface Science
Charles Paulson	Current Chemistry Ph.D. Graduate Student	NSOM Development
Jingxi Sun	ChE Graduate Student, Ph.D. granted	Growth of GaN and Material Modeling
Ling Zhang	Current Ph.D. ChE Graduate Student	MOVPE GaN

Other Personnel Impacted By and Participating in Research Supported by the Grant but not Receiving Support

Name	Position	Activity
Darren Hansen	ChE Graduate Student, Ph.D. granted	FTIR measurements
Jinag Li	ChE Graduate Student, Ph.D. granted	Interfacial Chemistry
Chih-huh Wei	Postdoctoral Researcher	Interfacial Chemistry
Rong Zhang	Visiting Scientist	Defect Chemistry

Inventions Reported

No inventions reported during the grant period.

Technology Transfer

The interactions with Lumileds were developed in the study of oxygen-based defects. We have had joint projects on the nature of defects in GaN with Lucent Bell labs. We continued the active collaboration with Prof. Charles Winter (Wayne State University) and carried out joint work with Prof. Stephen Bishop (U. Ill.- Urbana).